TRANSPORTATION AND AIR QUALITY: A METROPOLITAN PERSPECTIVE

METROPOLITAN AREAS EXPERIENCE THE MOST ACUTE TRANSPORTATION-RELATED AIR POLLUTION IMPACTS. COMMUTING, SHOPPING, AND OTHER SHORT PERSONAL TRIPS IN HIGHWAY VEHICLES CAUSE MOST OF THESE IMPACTS. THIS CHAPTER DISCUSSES AIR QUALITY TRENDS IN U.S. METROPOLITAN AREAS, ANALYZES FACTORS THAT UNDERLIE THESE TRENDS, SUCH AS TRANSPORTATION ACTIVITY AND emissions rates, and discusses transportation control measures (TCMs) and their potential to mitigate the impact of transportation on air quality in metropolitan areas.

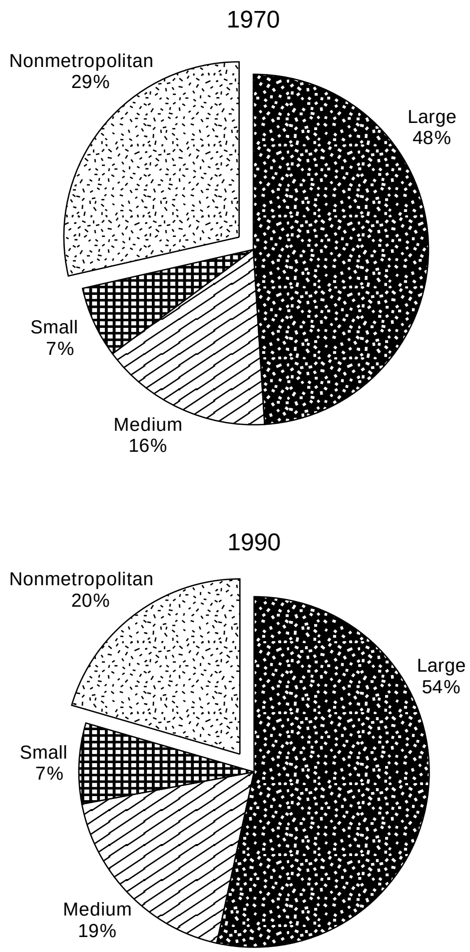
About 80 percent of the U.S. population lived in 268 metropolitan statistical areas (MSAs) in 1990.[1] The MSAs range in size from almost 20 million people (the New York-Northern New Jersey-Long Island consolidated MSA) to less than 200,000 people. (USDOC 1994a, 37, 39–41) A growing proportion of people live in large (population over 1 million) and medium-size (250,000 to 999,999) metropolitan areas (see figure 8-1).

Between 1985 and 1994, some of the fastest growing metropolitan areas (San Diego, Dallas, Houston) had the highest percentage reductions for the primary air pollutants from highway vehicles.

The central cities of MSAs are focal points for various types of economic and social interactions, such as commuting

[1] The Bureau of the Census defines MSAs as containing a central city of at least 50,000 population and all those surrounding urbanized counties that are strongly linked with it. Large MSAs that include two or more adjacent cities of over 50,000 population are designated consolidated metropolitan statistical areas.

FIGURE 8-1: U.S. POPULATION LIVING IN METROPOLITAN AREAS BY SIZE AND IN NONMETROPOLITAN AREAS, 1970 AND 1990



SOURCE: U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1994* (Washington, DC: 1994), table 40.

and shopping trips. Surrounding suburban communities with lower development densities are strongly linked with the central city and with each other. Commuting patterns are a good indicator of the strength of these linkages. Metropolitan areas are usually delineated so that most commuting trips occur within their borders rather than across them.

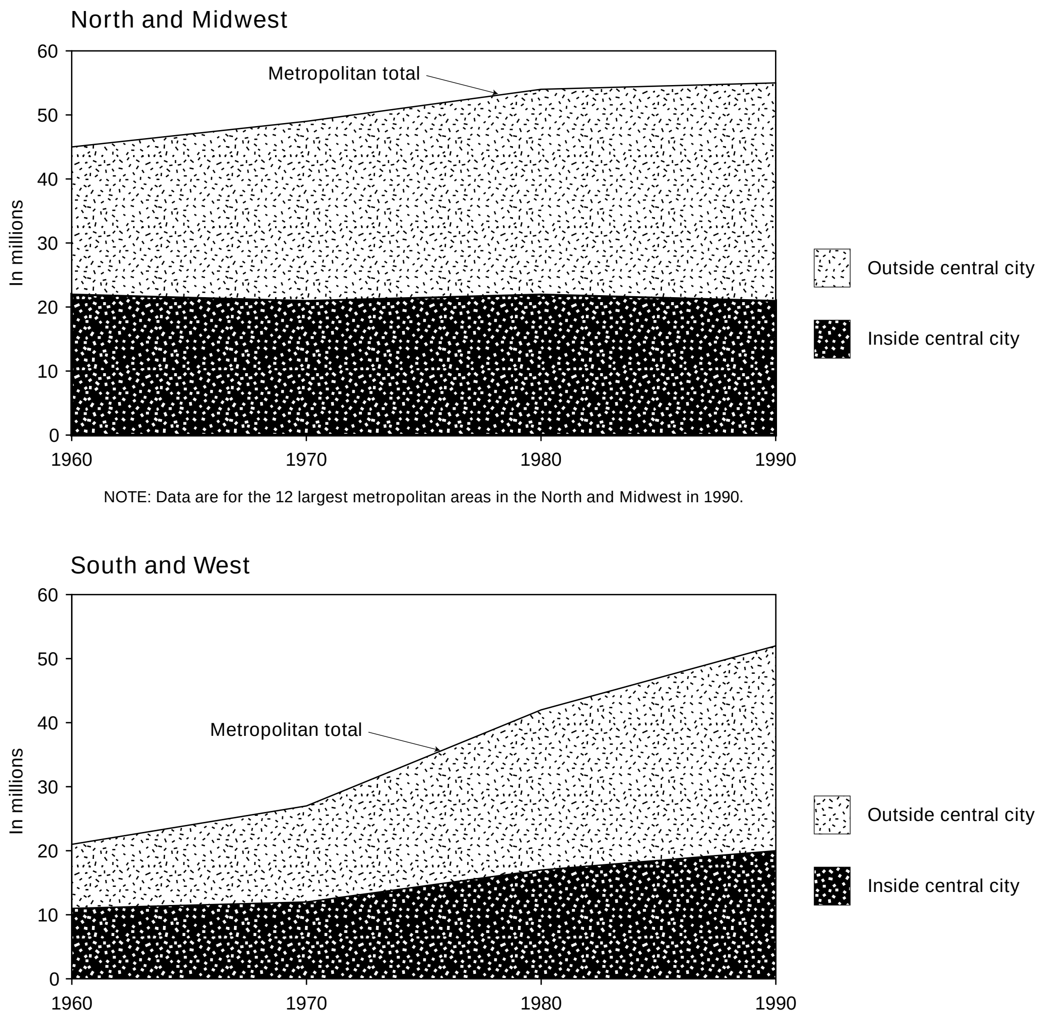
MSAs vary widely in rates of population growth. In general, southern and western metropolitan areas grew rapidly between 1970 and 1990. For example, Miami's metropolitan population grew by 40 percent between 1970 and 1980 and by another 21 percent in the 1980s. Northern cities generally declined or marked much smaller gains in this period. The New York metropolitan area, for instance, declined by 4 percent between 1970 and 1980 but grew by 3 percent between 1980 and 1990.

Most MSA population growth has occurred in the suburbs, with central cities either growing more slowly or declining in population (see figure 8-2). Even in some rapidly growing western metropolitan areas, where central cities have been growing at double-digit rates, suburbs have grown more quickly. Suburbs have also enjoyed relatively greater growth in jobs, retail outlets, and recreational facilities, placing further pressure on the development of the rural periphery. The result is a decline in the density of both population and employment—a trend strengthened by the faster growth in the newer, low-density metropolitan areas of the South and West.

As the metropolitan population share increased and the density of development within metropolitan areas decreased, the proportion of travel occurring within metropolitan areas grew. The urban area portion of automobile vehicle-miles traveled (vmt) increased from 48 percent in 1960 to 65 percent in 1994. Similarly, the urban area portion of truck vmt increased from 35 percent to 54 percent over the same period.[2] (USDOT FHWA various years)

[2] In this case *urban* includes some smaller urbanized areas, but is dominated by the metropolitan areas.

FIGURE 8-2: POPULATION CHANGE IN CENTRAL CITIES AND METROPOLITAN AREAS, 1960–90



NOTE: Data are for the 12 largest metropolitan areas in the North and Midwest in 1990.

NOTE: Data are for the 13 largest metropolitan areas in the South and West in 1990.

SOURCE: U.S. Department of Commerce, Bureau of the Census, *State and Metropolitan Area Data Book* (Washington, DC: U.S. Government Printing Office, 1979 and 1991).

Metropolitan Emissions and Air Quality

The Clean Air Act established National Ambient Air Quality Standards (NAAQS) for six pollutants (called criteria pollutants). The standards are used to characterize the relative healthiness of air quality depending on the concentrations of these pollutants in the air (see box 8-1). The U.S. Environmental Protection Agency (EPA), states, and localities have set up a nationwide system of air quality monitoring stations. The stations measure ambient concentrations of the six criteria pollutants, so that peak-levels can be judged for conformity with air quality standards.

Box 8-1: Air Quality Standards and Attainment Levels

The National Ambient Air Quality Standards (NAAQS) are a set of atmospheric concentration levels (not to be confused with emissions levels) for six critical air pollutants: carbon monoxide (CO), lead, nitrogen dioxide (NO_2), ozone (O_3), fine particles (PM-10), and sulfur dioxide (SO_2). These standards are defined by the U.S. Environmental Protection Agency (EPA) as concentration levels above which there is significant damage to public health and welfare. Primary standards protect against adverse health effects, while secondary standards protect against other effects, such as damage to vegetation and buildings. Current primary and secondary standards are shown in the table.

Since there may be significant day-to-day or even hour-to-hour variation in air quality, standards for some pollutants are defined in terms of peak periods. Health impacts are more closely connected with the worst concentration levels than with average levels. For example, the standard for CO is not attained if the eight-hour concentration level is exceeded during any eight-hour period within a year, or if the higher one-hour concentration level is exceeded during any one-hour period. For O_3 the standard is not attained if the maximum one-hour concentration exceeds the standard more than one day a year.[1]

Monitoring of ambient concentrations takes place at over 4,000 monitoring sites, known as the Aerometric Information Retrieval System, operated mostly by state and local agencies. While not all sites monitor each pollutant, each is monitored at 300 or more sites.

Areas where concentrations of one or more pollutants persistently exceed the standards levels are designated as nonattainment areas. A nonattainment area is classified as marginal, moderate, serious, severe, or extreme depending on the number of days and the amount by which the concentration standards are exceeded. In nonattainment areas, steps must be taken to reduce emissions. As of February 8, 1996, there were 182 regions designated as nonattainment areas for one or more of the six pollutants: 75 for O_3, 35 for CO, 43 for

[1] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Quality and Emission Trends Report, 1992*, EPA-454/R-93-031 (Research Triangle Park, NC: October 1993).

National Ambient Air Quality Standards

	Primary standard		Secondary standard	
Pollutant	**Type of average**	**Standard level concentration**	**Type of average**	**Standard level concentration**
Carbon monoxide	8-hour 1-hour	9 ppm 35 ppm	No secondary standard No secondary standard	
Lead	Maximum quarterly average	1.5 ug/m	Same as primary standard	
Nitrogen dioxide	Annual arithmetic mean	0.053 ppm	Same as primary standard	
Ozone	Maximum daily 1-hour average	0.12 ppm	Same as primary standard	
PM-10	Annual arithmetic mean 24-hour	50 ug/m 150 ug/m	Same as primary standard Same as primary standard	
Sulfur dioxide	Annual arithmetic mean 24-hour	80 ug/m 365 ug/m	3-hour	1,300 ug/m

KEY: ppm = parts per million; ug/m = micrograms per cubic meter.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Quality and Emissions Trends Report, 1992* (Research Triangle Park, NC: 1993).

Box 8-1 (cont'd): Air Quality Standards and Attainment Levels

SO_2, 82 for PM-10, 10 for lead, and 1 for NO_2.[2] The great majority of the population living in nonattainment areas is metropolitan.

The number of people exposed to unhealthy air in nonattainment areas is difficult to estimate. A total of 132 million people live within the boundaries of the 182 nonattainment areas. Yet, this is not necessarily a good measure of the number of people currently exposed to unhealthy air. To be reclassified as in attainment, an area must not violate EPA standards for three consecutive years and must have an approved state implementation plan (SIP). Thus, some areas may not have violated air quality standards for one or two years but will still be classified as nonattainment. An estimated 90 million people live within the boundaries of nonattainment areas that currently violate EPA standards. Some of these people have homes located in healthy air pockets, even though the metropolitan region as a whole is in nonattainment. (They may still be affected if they work in areas with unhealthy air.) EPA also estimates the number of people living in counties with unhealthy air in a single year. Data for the most recent year available, 1994, show that 62 million live in counties that violated at least one pollutant standard.[3] This estimate, however, only includes counties that have a monitoring station and does not account for year to year weather variations that can affect air quality. Consequently, this method likely underestimates the number of people who live in areas with unhealthy air.

[2] An updated list of nonattainment areas is available on the World Wide Web at www.epa.gov/airs/nonattn.html.

[3] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollution Emission Trends, 1900–1994*, EPA-454/R-95-011 (Research Triangle Park, NC: October 1995).

Estimating the number of people that are exposed to unhealthy air is difficult, however. It is currently estimated that between one-quarter to one-third of the population are affected. Most live in urban areas.

Transportation vehicles—especially highway vehicles—emit large quantities of four pollutants that are directly covered by the NAAQS or are related precursor substances. As detailed in chapter 7, much progress has been made in reducing emissions from highway vehicles. In 1994, however, highway vehicles still accounted for 62 percent of carbon monoxide (CO) emissions, 32 percent of nitrogen oxides (NO_x) emissions, and 7 percent of particulate matter smaller than 10 microns (PM-10) excluding miscellaneous and natural sources. Highway vehicles also accounted for 26 percent of volatile organic compounds (VOCs) emissions, which along with NO_x are the main precursor pollutants to ozone (O_3) formation. (USEPA 1995)

Table 8-1 shows estimates of highway vehicle emissions in 13 MSAs in 1985 and in 1994. Over that period, significant reductions occurred in the primary pollutants, except NO_x which increased in some areas. Some of the fastest growing metropolitan areas (San Diego, Dallas, Houston) were among those with the highest percentage reductions for these pollutants.

Because of differences in transportation patterns and economic structure among metropolitan areas, the proportion of emissions attributable to highway vehicles varies. In San Francisco, for example, 79 percent of estimated CO emissions are attributed to road vehicles, along with 46 percent of both NO_x and VOC emissions. By contrast, only 60 percent of CO, 25 percent of NO_x, and 17 percent of VOC are attributed to road vehicles in Houston, possibly owing to the predominance of petroleum-based industries in that area. (USEPA 1995, table 2-7)

The link between vehicle emissions and concentrations in the air is not straightforward. Local factors, such as variations in weather and topography, affect the rate of emissions dispersal. Moreover, the size of the area over which

Table 8-1: Transportation Emissions for Selected Areas, 1985–94
(thousand short tons per year)

Region	Metropolitan area		VOC	NO_x	CO	PM-10
North	New York-Northern New Jersey-	1985	447	356	3,552	14.6
	Long Island CMSA (partial[a])	1994	301	329	2,620	12.0
		Change (percent)	–32.7	–7.3	–26.2	–17.9
	Chicago-Gary-	1985	267	186	2,249	7.4
	Lake County, IL-IN-WI CMSA	1994	160	168	1,547	6.0
		Change (percent)	–39.9	–9.5	–31.2	–18.9
	Pittsburgh-Beaver Valley, PA CMSA	1985	87	69	737	2.9
		1994	47	51	465	2.0
		Change (percent)	–46.0	–26.1	–36.9	–31.0
	Indianapolis, IN MSA	1985	48	39	396	1.6
		1994	39	40	389	1.5
		Change (percent)	–20.1	3.0	–1.7	–4.9
South	Dallas-Fort Worth, TX CMSA	1985	179	124	1,370	5.3
		1994	96	102	891	4.0
		Change (percent)	–46.4	–17.4	–34.9	–24.7
	Houston-Galveston-Brazoria, TX CMSA	1985	172	124	1,319	5.4
		1994	100	105	956	4.1
		Change (percent)	–41.9	–15.3	–27.5	–34.1
	Miami-Fort Lauderdale, FL CMSA	1985	119	64	841	2.8
		1994	78	68	722	2.6
		Change (percent)	–34.9	6.3	–14.1	–7.1
	Tampa-St. Petersburg-	1985	89	54	633	2.5
	Clearwater, FL MSA	1994	52	53	484	2.2
		Change (percent)	–41.7	–1.6	–23.5	–12.6
West	Los Angeles-Anaheim-	1985	417	329	3,185	15.3
	Riverside, CA CMSA	1994	285	300	2,361	12.5
		Change (percent)	–31.7	–8.8	–25.9	–18.3
	San Francisco-Oakland-	1985	185	165	1,476	7.6
	San Jose, CA CMSA	1994	130	139	1,148	5.7
		Change (percent)	–30.1	–15.8	–22.2	–24.6
	Seattle-Tacoma, WA CMSA	1985	98	96	870	3.9
		1994	70	87	667	3.3
		Change (percent)	–28.3	–8.9	–23.3	–16.8
	San Diego, CA MSA	1985	74	65	563	3.0
		1994	49	55	392	2.4
		Change (percent)	–34.8	–15.2	–30.4	–22.1
	Portland-Vancouver, OR-WA CMSA	1985	42	43	347	1.8
		1994	30	41	268	1.6
		Change (percent)	–28.4	–5.2	–22.7	–12.6

[a]Contains only Fairfield County, Connecticut. 1990 census definition also includes parts of Litchfield and New Haven counties.

KEY: CMSA = consolidated metropolitan statistical area; MSA = metropolitan statistical area.

NOTE: Metropolitan definitions used in this table do not necessarily correspond to metropolitan definitions used to define nonattainment areas. Thus, the emissions numbers in this table cannot be used to assess compliance with federal clean air requirements.

SOURCE: County-level data provided by the U.S. Environmental Protection Agency aggregated up to MSAs according to 1990 census definitions.

emissions are distributed affects concentration levels. Both San Francisco and Houston have very high levels of CO emissions, but relatively low CO concentrations in the air. NO_x and VOC are precursors to ozone, yet St. Louis, with relatively low emissions of both pollutants has a high ozone concentration (see table 8-2).

EPA's pollution standards index (PSI) provides a daily indicator of an area's overall air quality. The index values range from 0 to 500, with values above 100 indicating increasingly unhealthful air quality. Although all criteria pollutants are included in the PSI, high levels of O_3 account for most of the daily PSI values greater than 100. Table 8-3 shows the number of days in which the PSI exceeded 100 in a selection of MSAs.

The most striking aspect of table 8-3 is the general downward trend in unhealthful days for most metropolitan areas. The improvement is evident even in fast-growth areas such as Miami, San Diego, Phoenix, and Denver—indicating that growth in population does not necessarily lead to more days of unhealthy air quality. These downward trends are consistent with the national trends presented in chapter 7.

Variability is also evident in tables 8-2 and 8-3. Los Angeles has high concentration levels for all pollutants and air quality that is unhealthful or worse on roughly half the days of most years, while Miami has concentrations roughly half as high as in Los Angeles and healthful to moderate air nearly all year round.

Table 8-3 also shows that cities with similar peak concentration profiles may be quite different in terms of the frequency of unhealthful air. For example, peak concentrations in Baltimore and in Philadelphia are not very different, yet Baltimore had almost three times as many days with unhealthful air in 1994.

It is important to recognize that not all the environmental impacts of urban transportation are reflected in metropolitan air quality indicators. Other impacts, such as the contribution of NO_x and VOC emitted from road vehicles to the problems of acid deposition and the contribution of CO_2 from vehicles to climate change may affect the environment at the continental and global scales (see discussion of greenhouse gas emissions in chapters 7 and 9).

Road Vehicles and Air Quality

What factors underlie the downward trend in highway vehicle emissions across the diverse cross section of U.S. metropolitan areas shown in table 8-1? As discussed below, levels of emissions from road vehicles are a reflection of two factors: the total amount of driving, and the rate of emissions on a per vehicle-mile traveled (vmt) or per trip basis.

► Transportation Trends

Transportation analysts generally divide the pattern of urban trip-making into four stages: trip generation, trip distribution, mode split, and traffic assignment. Trip generation refers to the number of trips made by residents of each part of the city at various times of the day. Trip distribution refers to the destinations they choose, and thus determines the average length of trips. Mode split refers to the decision to travel by car, carpool, public transportation, bike, or on foot, thus establishing the relationship between passenger-miles traveled and miles traveled by each type of vehicle. Traffic assignment refers to the combined routing of all vehicles onto the roads and rails that make up the urban transportation network. The relationship between the capacity of that network and the number of vehicle-trips assigned to it over any interval of time affects the level of congestion.

The rate of trip generation has been increasing. The Nationwide Personal Transportation Survey (NPTS), which provides the most com-

Table 8-2: Pollutant Concentrations in Selected Areas, 1994

Region	PMSA[a]	CO (ppm)	NO_2 (ppm)	Ozone (ppm)	PM-10 (ug/m)
North	New York, NY	7	0.046	**0.13**	**53**
	Chicago, IL	8	0.034	0.12	44
	Philadelphia, PA-NJ	8	0.037	**0.13**	**111**
	Detroit, MI	**10**	0.025	**0.14**	49
	Boston, MA-NH	6	0.035	0.12	29
	Cleveland-Lorain-Elyria, OH	8	0.028	**0.13**	**60**
	Minneapolis-St. Paul, MN-WI MSA	6	in	0.08	in
	St. Louis, MO-IL MSA	6	0.028	**0.15**	45
	Pittsburgh, PA MSA	7	0.031	0.12	41
	Cincinnati, OH-KY-IL	5	0.027	**0.13**	32
	Milwaukee-Waukesha, WI	7	0.025	**0.13**	33
	Kansas City, MO-KS MSA	5	0.011	0.11	40
South	Washington, DC-MD-VA-WV	6	0.030	**0.13**	29
	Dallas, TX	5	0.016	**0.14**	29
	Houston, TX	6	0.028	**0.17**	47
	Miami, FL	5	0.014	0.11	25
	Atlanta, GA MSA	5	0.023	**0.13**	32
	Baltimore, MD	7	0.032	**0.15**	33
	Tampa-St. Petersburg-Clearwater, FL	4	0.010	0.10	30
West	Los Angeles-Long Beach, CA	**15**	0.050	**0.24**	47
	San Francisco, CA	5	0.022	0.08	in
	Seattle-Bellevue-Everett, WA	7	nd	**0.13**	28
	San Diego, CA MSA	7	0.024	**0.14**	**51**
	Phoenix-Mesa, AZ MSA	**10**	in	0.12	50
	Denver, CO	8	0.035	0.11	36
	Portland-Vancouver, OR-WA	8	in	0.11	32
	Honolulu, HI MSA	5	0.004	0.06	17
	Anchorage, AK MSA	**11**	nd	nd	in

[a]MSA where noted; definitions are based on Office of Management and Budget definitions effective June 30, 1993.
KEY: PMSA = primary metropolitan statistical area; MSA = metropolitan statistical area; ppm = parts per million; ug/m = micrograms per cubic meter; in = insufficient data; nd = no data.

NOTE: **Numbers in bold** indicate that MSA is a nonattainment area.
Basis of concentration measure:
CO: Second highest maximum non-overlapping 8-hour concentration.
NO_2: Highest arithmetic mean concentration.
Ozone: Second highest daily maximum 1-hour concentration.
PM-10: Highest weighted annual mean concentration.

SOURCE: U.S. Environmental Protection Agency, *National Air Quality and Emissions Trends Report, Data Appendix* (Research Triangle Park, NC: 1994), table A-12.

TABLE 8-3: NUMBER OF PSI DAYS GREATER THAN 100 FOR SELECTED AREAS, 1985–94

Region	PMSA[a]	1985	1989	1994
North	New York, NY	65	18	8
	Chicago, IL	9	4	8
	Philadelphia, PA-NJ	31	20	6
	Detroit, MI	2	10	8
	Boston, MA-NH	3	4	1
	Cleveland-Lorain-Elyria, OH	1	6	4
	Minneapolis-St. Paul, MN-WI MSA	22	5	3
	St. Louis, MO-IL MSA	10	13	11
	Pittsburgh, PA MSA	9	9	2
	Cincinnati, OH-KY-IL	5	3	5
	Milwaukee-Waukesha, WI	5	8	4
	Kansas City, MO-KS MSA	3	2	0
South	Washington, DC-MD-VA-WV	17	8	7
	Dallas, TX	27	7	1
	Houston, TX	64	42	29
	Miami, FL	5	4	0
	Atlanta, GA MSA	9	3	4
	Baltimore, MD	25	9	17
	Tampa-St. Petersburg-Clearwater, FL	6	1	0
West	Los Angeles-Long Beach, CA	208	226	136
	San Francisco, CA	5	1	0
	Seattle-Bellevue-Everett, WA	25	8	0
	San Diego, CA MSA	88	90	16
	Phoenix-Mesa, AZ MSA	88	30	7
	Denver, CO	38	11	2
	Portland-Vancouver, OR-WA	3	6	2
	Honolulu, HI MSA	0	0	0

[a]MSA where noted; definitions are based on Office of Management and Budget definitions effective June 30, 1993.

KEY: PSI = pollution standards index; PMSA = primary metropolitan statistical area; MSA = metropolitan statistical area.

SOURCE: U.S. Environmental Protection Agency, *National Air Quality and Emissions Trends Report, Data Appendix* (Research Triangle Park, NC: 1994), table A-13.

prehensive data about urban trips, found that between 1983 and 1990 the number of person-trips in the United States grew by 11 percent, at a time when the population grew by only 4 percent. (USDOT FHWA 1993, 4-4) Family and personal business (including shopping) were the fastest growing trip categories.

Due in part to the gradual decentralization of metropolitan areas, the trend in trip distribution is toward more distant destinations. Trip length for all purposes in metropolitan areas increased from an average of 8.5 miles in 1983 to 9.3 miles in 1990, a 9.4 percent increase. (USDOT FHWA 1993, 4-42) If the average metropolitan trip length in 1990 had remained at the 1983 level of 8.5 miles, Americans would have traveled 156 billion miles less in metropolitan areas than they did in 1990. Trips associated with earning a living increased in length by 19 percent over this period.

Table 8-4 shows changes in the duration of work trips for 26 metropolitan areas. Since changes in the level of congestion as well as changes in trip length can affect duration, these data are an imperfect indicator of trip length. Trip duration generally increased the most in fast-growth metropolitan areas. There are exceptions, however. Milwaukee, which had slow population growth, had a significant increase in trip duration, while Denver, which had fast growth, had a very small increase.

Mode split is dominated by privately operated vehicles, which accounted for 86 percent of all urban trips in 1990—up from 81 percent in 1983. In the same period, the share of trips made on public transportation fell from 3.4 percent to 2.6 percent and the percentage of trips made by other modes—bicycle, walking, school bus, taxi, airplane, rail, moped—fell from 13.1 percent of all trips to 11.7 percent. Public transportation's share of total trips declined for two reasons: first because the transit share declined for most categories of trips, and second because the fastest growing category of trips—family and personal business—is also the category for which travelers are least likely to use transit. The greatest transit share is in the Boston-to-Wash-

TABLE 8-4: MEAN TRAVEL TIMES TO WORK IN SELECTED AREAS, 1980–90 (IN MINUTES)

Region	Area	1980	1990	Change (percent)
North	New York-Northern New Jersey-Long Island CMSA	33.7	31.1	–7.7
	Chicago-Gary-Lake County, IL-IN-WI CMSA	26.3	28.1	6.7
	Philadelphia-Wilmington-Trenton, PA-NJ-DE-MD CMSA	24.0	24.1	0.5
	Detroit-Ann Arbor, MI CMSA	22.5	23.4	3.8
	Boston-Lawrence-Salem, MA-NH CMSA	23.4	24.2	3.6
	Cleveland-Akron-Lorain, OH CMSA	21.6	22.0	1.7
	Minneapolis-St. Paul, MN-WI MSA	20.1	21.1	4.9
	St. Louis, MO-IL MSA	22.6	23.1	2.3
	Pittsburgh-Beaver Valley, PA CMSA	22.8	22.6	–1.1
	Cincinnati-Hamilton, OH-KY-IN CMSA	21.8	22.1	1.4
	Milwaukee-Racine, WI CMSA	18.8	20.0	6.2
	Kansas City, MO-KS MSA	20.7	21.4	3.6
South	Washington, DC-MD-VA MSA	27.2	29.5	8.5
	Dallas-Fort Worth, TX CMSA	22.4	24.1	7.4
	Houston-Galveston-Brazoria, TX CMSA	25.9	26.1	0.7
	Miami-Fort Lauderdale, FL CMSA	22.6	24.1	6.5
	Atlanta, GA MSA	24.9	26.0	4.6
	Baltimore, MD MSA	25.3	26.0	2.7
	Tampa-St. Petersburg-Clearwater, FL MSA	20.2	21.8	7.8
West	Los Angeles-Anaheim-Riverside, CA CMSA	23.6	26.4	11.9
	San Francisco-Oakland-San Jose, CA CMSA	23.9	25.6	6.9
	Seattle-Tacoma, WA CMSA	22.8	24.3	6.7
	San Diego, CA MSA	19.5	22.2	13.7
	Phoenix, AZ MSA	21.6	23.0	6.5
	Denver-Boulder, CO CMSA	22.0	22.4	1.9
	Portland-Vancouver, OR-WA CMSA	21.4	21.7	1.5

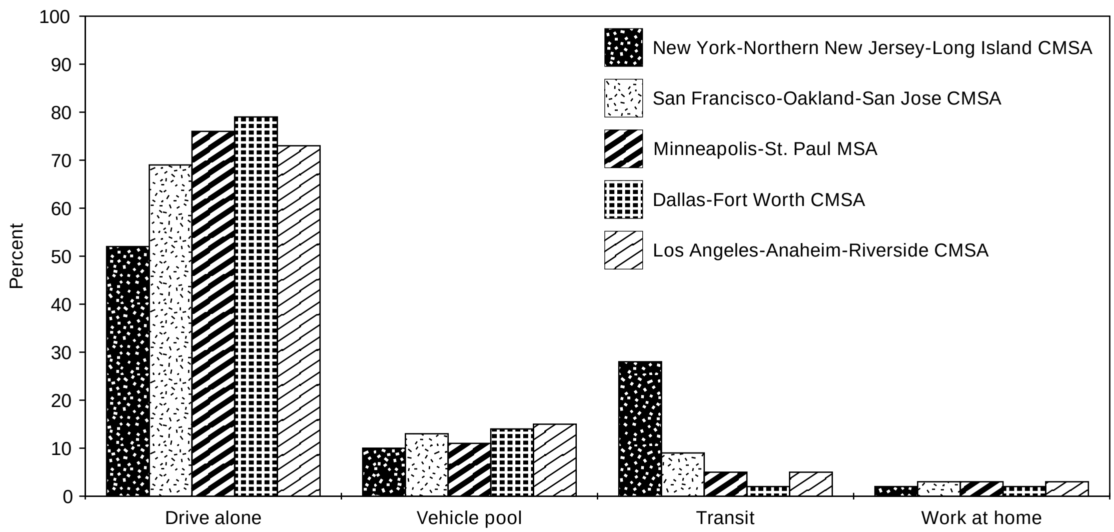
KEY: CMSA = consolidated metropolitan statistical area; MSA = metropolitan statistical area.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Journey-to-Work Trends in the United States and Major Metropolitan Areas, 1960–1990* (Washington, DC: 1993), table 4-13.

ington Corridor and in Chicago. New York has the greatest proportion of commuters who use transit (see figure 8-3).

In the rest of the country, San Francisco is the only major metropolitan area where transit share approaches 10 percent. In Minneapolis and Los Angeles the share is 5 percent and in Dallas only 2 percent. The fact that transit shares are low in rapidly growing metropolitan areas of the South and West reinforces the countrywide shift away from transit. Many people in such southern and western cities as Dallas and Los Angeles ride in

FIGURE 8-3: JOURNEY-TO-WORK MODE SHARES IN SELECTED MSAS, 1990



KEY: CMSA = consolidated metropolitan statistical area; MSA = metropolitan statistical area.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Journey-to-Work Trends in the United States and Major Metropolitan Areas, 1960–1990* (Washington, DC: November 1993), table 5-7.

vehicle pools, thus dampening the geographical variation in the drive alone mode share.

The increasing number of trips, distance of trips, and dominance of private modes of transportation have all led to an increase in vmt in privately operated vehicles. In urban areas, vmt increased 34 percent between 1983 and 1990. (USDOT FHWA 1994, 2-5, 2-6) There is, however, significant variation across metropolitan areas in road transportation. Newer, fast-growth areas such as Houston and Atlanta have a vehicle-mile per capita rate more than 50 percent higher than some older metropolitan areas such as Boston and Pittsburgh.

Finally, traffic growth is faster than growth in road capacity, leading to a potential for increased congestion in some areas. Between 1980 and 1992, total urban vmt increased by 61 percent while urban road mileage increased by only 26 percent. (USDOT FHWA various years) Wasted time and fuel are well documented costs of congestion. (Downs 1992) Cars traveling in congested traffic have higher emissions per mile than cars traveling at a moderate speed. CO, the greenhouse gas carbon dioxide (CO_2), and VOC emissions are especially high when cars accelerate or decelerate, and may be significantly higher when a car is idling than when it cruises at a steady speed. (TRB 1995, ch. 3) It is not clear, however, whether relieving congestion necessarily reduces emissions. Congestion is a major deterrence to driving, so reduced congestion may lead to increased vmt. Also, emissions of most pollutants, especially NO_x, increase above moderate speeds.

Empirical evidence on congestion is difficult to construct. Table 8-5 presents the Texas Transportation Institute's (TTI's) congestion index of U.S. cities. As the data show, most large cities have significant congestion problems, although some medium-size cities (e.g., Miami and Seattle) are more congested than some of

TABLE 8-5: ROADWAY CONGESTION INDEX, 1982–90

Region	Urban area	1982	1990	Change (percent)
North	New York	1.01	1.14	13
	Chicago	1.02	1.25	23
	Philadelphia	1.00	1.05	5
	Detroit	1.13	1.09	–4
	Boston	0.90	1.06	18
	Cleveland	0.80	0.97	21
	Minneapolis-St. Paul	0.74	0.93	26
	St. Louis	0.83	0.99	19
	Pittsburgh	0.78	0.82	5
	Cincinnati	0.86	0.96	12
	Milwaukee	0.83	0.99	19
	Kansas City	0.62	0.74	19
South	Washington, DC	1.07	1.37	28
	Dallas	0.84	1.05	25
	Houston	1.17	1.12	–4
	Miami	1.05	1.26	20
	Atlanta	0.89	1.11	25
	Baltimore	0.84	1.01	20
	Tampa	0.94	1.05	12
West	Los Angeles	1.22	1.55	27
	San Bernardino-Riverside	1.09	1.19	9
	San Francisco-Oakland	1.01	1.35	34
	Seattle	0.95	1.20	26
	San Diego	0.78	1.22	56
	Phoenix	1.15	1.03	–10
	Denver	0.85	1.03	21
	Portland	0.87	1.07	23
	Average	0.93	1.10	

NOTE: A value of 1.00 or greater indicates area-wide congestion. *Urban areas* are in some cases smaller than consolidated metropolitan statistical areas.

SOURCE: Texas Transportation Institute, *Estimation of Roadway Congestion, 1990* (College Station, TX: March 1994), table 6.

the largest cities (e.g., Philadelphia and New York). The TTI index indicates increasing congestion between 1982 and 1990 in all but three of the metropolitan areas.

TTI compares traffic count data with road capacity measures to construct the congestion index. Unfortunately, the resulting estimates do not correlate well with self-reported data from the NPTS. In that survey, respondents are asked to report the length and duration of trips. These can be used to calculate the average speed over each trip, which is a proxy for the level of congestion. The NPTS found a general increase in speeds. For instance, in cities of more than 3 million people, the mean work trip speed during the morning peak period for those living outside the central city increased from 28.1 mph in 1983 to 31.8 mph in 1990. The NPTS found similar or larger gains in cities of other sizes and for residents living inside the central city. This change is attributed to a decentralization of employment, which results in diversion of work trips away from those roads that are already most congested. (Gordon and Richardson 1994) There is some evidence to suggest, however, that congestion is not limited to high-density central areas. A recent study of the Chicago metropolitan area found that drivers in new, lower density suburbs were exposed to levels of congestion similar to those experienced by drivers in older suburbs closer to the urban core. (Prevedouros and Schofer 1991)

Given the contradictory nature of the best available data and the critical role of congestion in emissions generation, urban traffic congestion is a key area for further data development.

► Emissions Rates

Aside from the uncertainty about congestion, the preponderance of evidence is that urban driving increased in a period when highway vehicle emissions (other than NO_x) decreased and air quality improved significantly. Cars emit less pollution per mile than they did in the 1970s and early 1980s—reflecting the impact of federal emissions standards for new vehicles. As the stock of old cars turned over, the emissions performance of the in-service vehicle fleet improved. Beginning with the 1996 model year, emissions per mile standards for new cars and light trucks were cut by 39 percent for VOC and 60 percent for NO_x (the CO standard remained unchanged). Standards applying to the 2004 model year will be reduced by an additional 50 percent for all three pollutants, if EPA determines that it is necessary and feasible to do so. It must be noted, however, that past projections have proven to be optimistic. One reason is that real-world driving has produced more emissions than anticipated on the basis of testing data on emissions from new vehicles (see box 8-2).

Real-world emissions also could be affected by inspection and maintenance (I/M) programs. The 1970 Clean Air Act authorized EPA to require I/M programs for states that were unable to meet NAAQS for ozone or carbon monoxide. By 1996, I/M requirements affected 146 urban areas, of which 92 must implement enhanced I/M practices. (USEPA 1996) Over time, EPA changed its I/M guidelines to account for new vehicle technology and improved understanding of vehicle emissions. As a result, I/M procedures now may measure emissions under various speeds and engine loads, and check evaporative control systems. EPA's enhanced I/M guidelines also call for roadside monitoring of on-road emissions, such as by remote sensing devices that can estimate emission rates from passing vehicles. EPA estimates that enhanced I/M programs can reduce vehicle emissions by 31 percent for hydrocarbons and 34 percent for CO compared with no I/M, and by 26 percent and 18 percent, respectively, compared with older I/M procedures. (USEPA 1992, 2) In making these estimates, EPA attempts to account for real-world operating conditions, including the potential for errors in testing and repair.

EPA estimates the cost of enhanced I/M programs to be $460 to $2,000 per ton of VOC reduced, depending on assumptions about the frequency of testing, the allocation of costs to VOC and CO reductions, and other factors. (USEPA 1992, tables 6-4, 6-5, and 6-10) Other estimates are as much as 5 to 10 times higher, reflecting, among other things, different assumptions about the effectiveness of the I/M program and other emissions control programs in effect. (Anderson and Lareau 1992, McConnel and Harrington 1992)

Changes in the composition of fuel also have contributed to emissions reductions. Federal regulations require use of oxygenated gasoline during the winter months in 40 major metropolitan areas. Increasing the oxygen content in gasoline reduces CO and VOC emissions in laboratory tests (this has been verified in at least one field test). (Harley 1995)

Other gasoline reformulations may help address ozone problems. In response to the 1990 CAAA, refiners and automobile industry officials developed reformulated gasoline (RFG). These fuels are designed to meet limits on vapor pressure and toxic constituents, as well as oxygen requirements. (Lidderdale 1994) In 1995, RFG was introduced in nine cities with the highest ozone levels, as well as other ozone nonattainment areas that opted to participate in the program.

In the long term, technological advances could further reduce criteria emissions. The federal government and some states have sponsored or cost-shared research with industry on cleaner engine technologies, alternative fuel vehicles, and advanced emission control devices. (US Congress OTA 1995a) In time, such research could lead to new vehicles or fuels that are less polluting.

A critical question is whether technological advances will continue to reduce emissions, or at least hold them in check, for the foreseeable future. Recent nationwide data show increases in some criteria emissions from transportation between 1991 and 1994, as is discussed in detail in chapter 7. Whether these increases will continue, thus reversing the downward trend in the 1970s and 1980s, remains to be seen. A study by

Box 8-2: Real-World versus Expected Emission Rates

Studies of real-world vehicle emissions show that past estimates used in U.S. Environmental Protection Agency (EPA) models underestimated carbon monoxide (CO) and volatile organic compounds (VOC) emissions from motor vehicles.[1] EPA has since revised its emissions estimates upward. There are several reasons why real-world emissions have been higher than expected:

1. *Turnover of the vehicle fleet is slower than it once was*. In 1970, only 12 percent of cars and 29 percent of the light trucks were 10 or more years old. In 1993, by contrast, 30 percent of cars and 36 percent of light trucks were 10 or more years old. Old vehicles embody older, less effective technology than newer cars.

2. *Emissions controls become less effective as vehicles age.* EPA estimates that a properly operating 1995 vehicle after 50,000 miles of use will emit 2.3 times as much CO, 2.0 times as much VOC, and 1.3 times as much nitrogen oxides (NO_x) as when new.[2]

3. *Tampering with, or failing to maintain, emissions controls reduces their effectiveness.* Vehicles with disconnected catalytic converters emit 7 to 10 times as much CO and VOC. Tampering rates increase with vehicle age, from 1 to 7 percent for one-year-old cars to over 50 percent for nine-year-old vehicles.[3]

4. *Some vehicles, called "super-emitters," pollute much more than expected even when new.* The most recent studies show that 10 percent of vehicles emit almost 60 percent of the CO; and 10 percent (but not necessarily the same 10 percent) are responsible for 60 percent of VOC emissions.[4] This problem is not limited to the oldest vehicles. Among four-year-old cars, about two-thirds of CO emissions appear to come from the 10 percent of vehicles with malfunctioning emission controls.[5]

5. *The Federal Test Procedure (FTP)—used to certify newly manufactured vehicles for compliance with emissions regulations—does not fully reflect real-world driving conditions and behavior, thus creating a gap between the test and actual performance.* One problem is that certain speeds, acceleration rates, and other factors affecting vehicle emissions, are not represented in the FTP test cycle. One group of researchers estimates that over the lifetime of a 1993 model year car, about 46 percent of its CO and 7 percent of its hydrocarbon (HC) emissions will be due to such off-cycle operations. Emissions under these conditions are largely ignored by the regulatory process. Manufacturers, therefore, have been free to employ an engine-control strategy known as "command enrichment" under high-speed and high-acceleration off-cycle driving. Command enrichment provides excess fuel to the engine to improve drivability and reduce the chance of knocking under high load conditions. Some of this fuel exits the engine unburned. The catalytic converter's efficiency also is adversely affected. As a result, during command enrichment episodes, CO emissions per mile increase greatly.

6. *Other discrepancies between test assumptions and the real-world, such as the assumed effect of air conditioner use on emissions and the number of cold starts, lead to a performance shortfall.* EPA found that air conditioner use in vehicles has a greater effect on NO_x emissions than previously believed. In simulations of air conditioner operation in new vehicles at temperatures of 95°F, EPA found that NO_x emissions are an average of

[1] National Research Council, *Rethinking the Ozone Problem in Urban and Regional Air Pollution* (Washington, DC: National Academy Press, 1991), p. 300.

[2] U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources, Test and Evaluation Branch, *Compilation of Air Pollutant Emission Factors, Vol. 2, Mobile Sources,* AP-42 (Ann Arbor, MI: 1985).

[3] National Research Council, *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use,* Special Report 245, Transportation Research Board (Washington, DC: National Academy Press, 1995), p. 60 and table 2.

[4] B. Naghavi et al., "Remote Sensing Means, Medians, and Extreme Values: Some Implications for Reducing Automobile Emissions," *Transportation Research Record* No. 1416: Energy and the Environment, Transportation Research Board (Washington, DC: National Research Council, 1993), pp. 53–61.

[5] M. Ross et al., *Real-World Emissions from Model Year 1993, 2000 and 2010 Passenger Cars* (Washington, DC: American Council for an Energy Efficient Economy, 1995), p. 25.

Box 8-2 (cont'd): Real-World versus Expected Emission Rates

80 percent higher with an air conditioner in use.[6] At present, the FTP represents the effect of air conditioner use as a fixed percentage, giving manufacturers little incentive to optimize air conditioner designs for efficiency and emissions. Another discrepancy results from the amount of times a vehicle is started cold. For a cold start, excess fuel is added so that enough fuel vapor is present for steady combustion. While cold-start conditions are a part of the FTP, real-world driving surveys reveal that trips are shorter and cold starts more frequent than previously thought. Thus, more driving takes place before engines and catalysts reach normal operating temperatures than represented on the FTP. As a result, HC and CO emissions per mile are greater than previously believed.[7]

Although some of the causes of these discrepancies are still under study, EPA has proposed rules to address the discrepancy between FTP and real-world driving patterns and other factors, such as the effect of air conditioners. Documenting the extent of this problem and analyzing its causes and possible cures remains an important area for further research.

[6] J. German, "Off-Cycle Emission and Fuel Efficiency Considerations," paper presented at the 1995 Conference on Sustainable Transportation Energy Strategies, Asilomar Conference Center, California, July 31–Aug. 3, 1995.

[7] U.S. Environmental Protection Agency, Office of Radiation, *Federal Test Procedure Review Project, Preliminary Technical Report,* EPA-420-R-93-007 (Washington, DC: May 1993).

the Transportation Research Board of the National Academy of Sciences projected that, even with full achievement of all technological improvements mandated by current law, aggregate emissions of CO, VOC, and NO_x would increase if vmt grows just 2 percent per year. (TRB 1995) Higher rates of vmt growth (such as continuation of the 3.5 percent annual increase that occurred over the last decade) would lead to a more rapid increase in emissions.

A couple of notes of caution are in order. First, technological improvements other than those mandated in federal legislation may come into use in the coming years. The second is that demographic trends may lead to lower rates of growth in vmt. (See chapter 1 for a discussion of demographic trends). Nevertheless, the possibility exists that technological improvements will need to be complemented with other measures (such as TCMs) if continued progress is to be made in reducing emissions of most pollutants from highway vehicles.

► The Policy Context

Three federal laws significantly affect transportation planning to reduce emissions in metropolitan areas: The Clean Air Act and its 1990 Amendments (CAAA), the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), and the Energy Policy Act of 1992 (EPACT).

Under the CAAA, all metropolitan areas that do not meet the NAAQS are classified as marginal, moderate, serious, severe, or extreme nonattainment areas. (Once nonattainment areas meet standards they are classified as maintenance areas.) Nonattainment areas are required to take action to address their air pollution problems within a specified time period, depending on the relative severity of their problem. Thus, areas classified as marginal for ozone were given three years from the 1990 base year to attain standards, areas classified as moderate were given six years, areas classified as serious were given nine years, areas classified as severe were given 15 to 17 years, and the one extreme ozone nonattainment area (Los Angeles) was given 20 years. Those areas classified as moderate or worse were required to submit plans to reduce ozone precursors by 15 percent from the 1990 base within six years, and by 3 percent per year thereafter until standards are met. For severe or extreme nonattainment areas, these plans must include transportation control measures. (These measures are defined and described in the next section.)

Somewhat different rules apply for areas that are in nonattainment only for CO. Since CO is so closely linked with highway vehicles, these rules call for the adoption of TCMs when growth in vmt exceeds allowable levels. The sanctions for nonattainment areas that fail to comply with these rules include withholding of federal highway funds. (TRB 1995, 16–17) In addition, the CAAA requires state and metropolitan officials to demonstrate that all new transportation infrastructure projects in nonattainment and maintenance areas contribute to reductions in emissions.

ISTEA emphasizes integrated planning of different transportation modes, consideration of environmental impacts in plan assessment, and efficient provision of transportation services. (Gifford et al 1994, and Lyons 1994) ISTEA highlights the importance of metropolitan areas as planning units. It places new responsibilities on metropolitan planning organizations (MPOs), which represent local governments and public agencies within the metropolitan areas. To qualify for federal funds, each MPO must submit a long-range plan that includes environmental and intermodal considerations, and a transportation improvement program (TIP) with policy instruments and management tools to accomplish the plan's goals.

One objective of EPACT is to reduce U.S. dependence on imported petroleum by promoting use of alternative fuel vehicles. While EPACT is not, strictly speaking, environmental legislation, the effect of its requirements could be to reduce emissions in metropolitan areas.

Transportation Control Measures

Measures to reduce travel demand, improve traffic flow, divert travel away from peak periods, or mitigate harmful impacts of existing traffic are known collectively as transportation control measures. Metropolitan transportation planners have used TCMs in their efforts to reduce congestion for many years. The CAAA and ISTEA identified TCMs as important elements in an overall strategy to reduce emissions of pollutants from vehicles, especially in nonattainment areas. Some TCMs that reduce congestion, such as shifting trips to off peak, may have uncertain effects on emissions, however.

TCMs are used to encourage: 1) changes in mode choice—primarily to shift trips from single-occupancy vehicles (SOVs) to high-occupancy vehicles (HOVs) or transit; 2) changes in work day or work week trip scheduling by commuters; 3) flow improvements to reduce congestion levels without changing the number of vehicle trips; and 4) changes in vehicle stock to improve emissions performance. The first two address the level and pattern of travel demand, and are therefore known collectively as travel demand management (TDMs) measures, while the second two rely on improved systems management practices and vehicle technology.

TCMs can be implemented through several mechanisms. Information and education is used to publicize TCM programs and to prepare guidelines. Economic incentives may be used to promote desirable actions or discourage undesirable activities (see box 8-3). TCM implementation also can entail investment in public facilities, the transportation infrastructure, and systems management. Finally, regulations may be used to prohibit undesirable actions or require desired activities.

Table 8-6 classifies 15 kinds of TCMs according to the four categories of changes and implementation mechanisms described above.

Box 8-3: Congestion Pricing

Of all transportation control measures (TCMs), congestion pricing is often estimated to have the greatest potential to reduce volatile organic compounds (VOC) emissions. Also, unlike most TCMs, it can in theory not only reduce congestion levels, but lead to *optimal* congestion levels. It is not surprising, therefore, that it has been the subject of a great deal of interest and research in recent years.

In economist's language, congestion occurs as the result of a negative externality, which is an adverse impact that one person's behavior has on another person, and for which there is no compensation (see chapter 6 and appendix B for theoretical discussions of externalities). If a driver decides to take a trip, her presence in the flow of traffic will contribute marginally to the congestion delay that every driver on the road experiences. She is not required, however, to compensate the other drivers for the cost of the delay imposed by her presence. In other words, she is undercharged for the privilege of using the road. As is always the case, when a resource is underpriced, it is overused. Thus, an excessively large number of drivers choose to use the roads, and inefficient levels of congestion ensue. By setting a price that is equal to the marginal social cost, congestion pricing seeks to *internalize the externalities* in order to bring about efficient driving behavior.

If only the time costs of congestion are considered, the marginal social cost is equal to the total cost of delay (based on some estimate of the value of time) to *all* drivers on the roadway imposed by each additional driver. When environmental externalities are considered, calculation of the marginal social cost becomes considerably more complex. First, the social cost of emissions includes such disparate matters as health impacts and reductions in visibility. To calculate such costs, values would have to be assigned to human life and visual aesthetics—difficult and controversial matters. Furthermore, the relationship between the level of congestion and air quality is complex. Vehicles generally emit more at low and high speeds, so a reduction in congestion may have a deleterious effect beyond a certain point. For this reason, congestion pricing may only reduce emissions in a limited range of traffic situations.[1] Finally, the effects of changes in the rate and location of emissions on ambient air quality measures, such as ozone concentrations, is difficult to predict.

In addition to the problem of price setting, congestion pricing has practical drawbacks. People are always reluctant to pay a new tax. The case must be made that, despite the extra costs, commuters themselves would benefit from reduced congestion, and all urban residents would benefit from cleaner air. A second problem is how to collect such a tax. New technology allows the passage of a car over particular roadways to be recorded "on the fly" and the toll charged to the driver's account.[2] This technology is now used for congestion-sensitive pricing along a recently opened private toll road in Orange County, California.

Given both its potential and its problems, practical experience with road pricing is needed to assess the role it can play in mitigating urban air quality problems. The Intermodal Surface Transportation Efficiency Act of 1991 established a Congestion Pricing Pilot Program authorizing the Department of Transportation to enter into cooperative agreements with up to five state and local governments or other public authorities to establish, maintain, and monitor congestion pricing pilot projects. "Preproject" studies, including public outreach, project design, and related activities, can be supported with program funds. There are currently 10 congestion pricing projects funded under this program. Two of these are expected to lead to implementation of congestion pricing projects in the near future (San Diego, California, and Lee County, Florida). One project is monitoring and evaluating the privately constructed and operated variable toll facility in Orange County, California. The remaining seven projects are preproject studies examining alternative pricing approaches, including assessment of potential impacts and public participation in proposal development and project design. Several of these could proceed to implementation in the late 1990s.

[1] R. Guensler and D. Sperling, "Congestion Pricing and Motor Vehicle Emissions: An Initial Review," *Curbing Gridlock, Volume 2*, Transportation Research Board, Special Report 242 (Washington, DC: National Academy Press, 1994).

[2] K. Bhatt, "Potential of Congestion Pricing in the Metropolitan Washington Region," *Curbing Gridlock, Volume 2*, Transportation Research Board, Special Report 242 (Washington, DC: National Academy Press, 1994).

Table 8-6: Transportation Control Measures (TCMs)

TCM	Implementation mechanism	Examples
Commuter trip reduction	Information, education, and regulation	Ridesharing incentives, vanpool programs
Area-wide ridesharing	Information and education	Commuter-matching programs and databases
Rail transit improvement	Public facilities improvement	Light-rail system, expanded underground system
HOV lanes	Public facilities improvement	Lanes restricted to vehicles with three or more passengers
Park-and-ride lots	Public facilities improvement	Peripheral lots at transit stops or as car and vanpool staging areas
Bicycle/pedestrian facilities	Public facilities improvement	Pedestrian and bicycle lanes, bicycle lockers at transit stops
Parking pricing	Economic incentive	Charging full parking costs, parking "cash-back" program
Congestion pricing	Economic incentive	Charge for entering congested zone, congestion-based road pricing
Emissions/vmt tax	Economic incentive	Charged on gasoline or through differentiated registration fee
Buy-back of older cars	Economic incentive	Purchase of gross polluters above market value for scrapping
Compressed work week	Information and education	Employees work more hours on fewer days
Telecommuting	Information and education	Employees work at home or at "satellite" offices
Signal timing	Public facilities improvement	Timed lights to reduce accelerations and control access ramps
Incident management	Public facilities improvement	Automated monitoring, overhead signs to warn of incidents ahead
Land-use planning	Public facilities improvement, economic incentives, regulation	Increased density, nodal development, transit-oriented development

KEY: HOV = high-occupancy vehicle; vmt = vehicle-miles traveled.

SOURCE: Adapted from Apogee Research, Inc., *Cost and Effectiveness of Transportation Control Measures (TCMs): A Review and Analysis of the Literature*, prepared for the National Association of Regional Councils (Washington, DC: September 1994).

The final TCM in table 8-6 is land-use planning to reduce the need for automobile trips, decrease average trip lengths, and facilitate nonmotorized transportation. This longer term strategy is addressed in detail below.

The potential of TCMs to reduce total automobile emissions in metropolitan areas is disputed. Some critics argue that the benefits from TCMs may not justify the inconvenience to travelers. (Giuliano 1992) Furthermore, many analyses of TCMs have focused on their ability to reduce congestion (COMSIS Corp. 1993), which is not necessarily proportional to their ability to reduce emissions.

Apogee Research, Inc. recently reviewed the literature on use of TCMs to reduce VOC emissions, and their related costs. (Apogee Research, Inc. 1994) Table 8-7 shows key results of the study. Apogee identified what it considered to be a realistic maximum percentage reduction in trips, vmt, and VOC for each TCM. It evaluated information about the total capital, administrative, and operating costs of each TCM to estimate the cost per ton of VOC reduction. (The estimates do not include the full cost of tolls, taxes, and charges, or the costs of travel delay or lost productivity that might be associated with some TCMs.)

Where possible, the estimates were based on experience with TCMs. For example, data from California's South Coast Air Quality Management District (see box 8-4) were used to develop estimates of trip reductions arising from actions by employees. There has been, however, little or no application in North America of TCMs for congestion pricing, parking pricing, emissions/vmt taxes, telecommuting, signal timing, and incident management. In these instances, Apo-

TABLE 8-7: EFFECTIVENESS AND COST OF TRANSPORTATION CONTROL MEASURES
(RANKED BY COST PER TON)

	Vmt reduction (percent)		**Trip reduction** (percent)			
TCM	**Range of study estimates**	**Apogee estimate**	**Range of study estimates**	**Apogee estimate**	**VOC reduction** (percent)	**1994 cost per ton**
Emissions/vmt tax	0.2–0.6	0.4	0.1–0.9	0.7	4.1	near 0
Buy-back of older cars	na	na	na	na	0.4	3,000[a]
Area-wide ridesharing	0.1–2.0	0.4	0.5–1.1	0.3	0.4	16,000
Signal timing	<0.1	<0.1	<0.1	<0.1	0.4	23,000[b]
Parking pricing (work)	0.5–4.0	3.0	0.4–4.0	2.5	2.8	47,000
Congestion pricing	0.2–5.7	5.0	0.4–4.2	3.8	8.2	66,000
Incident management	(0.1)–0.0	–1.0	(0.1)–0.0	–1.0	0.8	83,000[b]
HOV lanes	0.2–1.4	1.4	0.5–0.6	0.5	1.1	109,000
Park-and-ride lots	0.1–0.5	0.5	0	0	0.3	146,000
Major rail transit improvement	0.0–2.6	1.0	0.6–2.5	0.8	0.9	272,000
Commuter trip reduction	0.2–3.3	1.0	0.1–4.1	0.8	0.9	281,000
Bicycle/pedestrian facilities	<0.1	<0.1	<0.1	<0.1	<0.1	289,000
Parking pricing (nonwork)	3.1–4.2	4.2	3.9–5.4	5.4	4.6	in
Telecommuting	0.0–3.4	1.1	0.0–2.8	1.0	1.0	in
Compressed work week	0.0–0.6	0.8	0.0–0.5	0.7	0.7	in

[a] For 1990.
[b] For 1997.

KEY: TCM = transportation control measure; vmt = vehicle-miles traveled; VOC = volatile organic compounds; na = not applicable; HOV = high-occupancy vehicle; in = insufficient data.

SOURCE: Based on Apogee Research, Inc., *Cost and Effectiveness of TCMs: A Review and Analysis of the Literature,* prepared for the National Association of Regional Councils (Washington, DC: January 1994).

gee used projections. As a result, caution should be used in interpreting the findings.

Some TCMs (including employee trip reduction, transit improvement, and bicycle/pedestrian facilities) were found to have relatively little potential for emissions reductions and were not cost-effective. Signal timing and incident management were relatively cost-effective, but also had little impact. Economic incentives (congestion pricing, parking pricing, and emissions/vmt taxes) ranked high in both potential reductions and cost-effectiveness. This conclusion, however, is based on projections rather than experience. Also, while taxes, tolls, and charges may have low systemwide costs, they have high direct costs to some individuals, and are likely to meet with political resistance.

The researchers concluded that TCMs aimed at inducing mode switches were ineffective because of the high premium that commuters place on driving alone. Also, existing TCMs focus on the journey to and from work, which limits their overall potential for emissions reduction. The study also was based on the application of TCMs in isolation from one another. In practice, more than one TCM might be implemented. For example, regional vanpool and parking cash-out programs might be applied together, as they have the common goal of reducing SOV commuting. It is not clear whether the combined emissions reductions would be greater (because of synergies) or less (because of overlap) than the sum of their individual effects. Also, imple-

Box 8-4: South Coast Air Quality Management District

Of all U.S. metropolitan areas, Los Angeles is the most severely affected by transportation-related air quality problems. Public concern over smog (of which ozone is a primary constituent) led to the establishment of the first air pollution control district in Los Angeles County in 1946. In 1976, the California legislature created the South Coast Air Quality Management District (SCAQMD). Its legal responsibility is to devise and implement plans to meet federal and state air quality standards in the region comprising Los Angeles, Orange, San Bernardino, and Riverside Counties—an area of over 12,000 square miles and the second most populous urban area in America.

SCAQMD has a legal mandate to achieve air quality objectives through a combination of planning, regulation, compliance assistance, enforcement, monitoring, technological advancement, and public education. Faced with such a heavy task, it is innovative in a number of ways. It collects a large proportion of its annual revenue of nearly $100 million through mechanisms to "make the polluter pay," including pollution fees and permits, and its mobile source programs are funded mostly from surcharges on vehicles. SCAQMD also pioneered the implementation of market-based pollution control mechanisms, including an emissions trading scheme for stationary sources.

Part of SCAQMD's effort focuses on *indirect sources* of air pollution—buildings or facilities that attract large numbers of highway vehicle-trips. Just as direct stationary sources are compelled to reduce their emissions, indirect sources, which include all major employers, are required to reduce emissions from the mobile sources that they attract. One of the most controversial of the efforts to regulate indirect sources was an employer trip reduction program known as Regulation XV. First implemented in 1987, but now rescinded, it required firms with over 100 employees to develop a plan to reduce single-occupancy vehicle trips in order to meet average vehicle ridership (AVR) targets within 24 months. Substantially higher than prevailing values, AVR targets varied from 1.3 riders per vehicle for firms located in rural fringe areas to 1.75 riders per vehicle near or in downtown Los Angeles. Firms were given flexibility to use measures to promote carpooling/vanpooling, transit use, and walk/bike options, as well as complementary measures such as parking cash-out, flexible schedules, and compressed work weeks. Roughly 6,000 firms with 2 million employees participated in Regulation XV programs.

Critics of Regulation XV contend that it interfered with business decisionmaking and that its contribution to emissions reductions did not justify its costs to the employers. Some held that SCAQMD overstated the potential for reduction in vehicle-miles traveled through trip reduction policies.[1]

In 1995, the California Legislature prohibited SCAQMD from enforcing mandatory trip-reduction programs, thus effectively rescinding Regulation XV. Under a new SCAQMD policy (Rule 2220), firms of more than 100 employees are given additional ways to achieve emissions reductions targets aside from AVR programs. For example, they could buy and scrap old vehicles belonging to their employees or subsidize the purchase of clean fuel vehicles. They can also pay $60 per employee to an Air Quality Investment Program in lieu of achieving the emissions target. Thus, a program based exclusively on trip reduction was replaced with a broader selection of transportation control measures and market-based instruments.

[1] C-H.C. Bae, "Air Quality and Travel Behavior: Untying the Knot," *Journal of the American Planning Association,* vol. 59, No. 1, 1993, pp. 65–75.

menting one TCM might affect the cost of implementing another.

When compared with the potential emissions reductions to be achieved through technological means, the contribution of TCMs appear modest. Some might conclude that TCMs are relatively unimportant and should therefore be given less emphasis than they now receive. It could be argued, though, that more effective TCMs need to be devised since emissions gains from technological improvements may be offset by even modest growth in vmt.

TCMs and technological progress are not, of course, mutually exclusive options. Moreover, a new class of technological innovations known collectively as intelligent transportation systems (ITS) may aid in the implementation of TCMs. These innovations include automated transaction systems that can charge tolls, transit fares, and parking fees without slowing down traffic; sophisticated systems management technologies that can adjust ramp controls and signal timing based on current sensor information about traffic conditions and incidents, and traveler information systems that provide current traffic conditions on an ongoing basis so that travelers can adjust the route, time, or mode of travel to avoid congestion delay. (US Congress OTA 1995b) These technologies could reduce the cost and inconvenience of implementing TCMs based on economic incentives, such as congestion pricing. They also could make TCMs relying on information exchange, such as ridesharing, more effective.

The overall impact of ITS on emissions is difficult to evaluate. A goal of ITS is to make the transportation network more efficient by reducing congestion and delays. Since vehicles emit fewer pollutants per gallon in steady or free-flow conditions than in stop-and-go conditions, these systems may reduce emissions rates. It is also possible that, if ITS improves driving conditions, people may drive more than they would under congested conditions and/or stop using high-occupancy vehicles.

The CAAA calls for the adoption of TCMs in nonattainment regions. Box 8-5 describes the process of TCM assessment for the strategy currently being applied to bring Washington, DC, in line with federal air quality standards. This example reinforces the observation that, despite the cost-effectiveness of certain TCMs, their contribution to emissions reduction is relatively small.

Urban Form, Infrastructure, and Air Quality

Urban form is the spatial configuration of fixed elements in a metropolitan area. These include land-use elements, such as buildings, parks, and public facilities, and transportation network elements, such as railways, roads, bridges, and terminal facilities. Urban form greatly influences transportation flows within metropolitan areas. Commuting patterns, for example, can be partly explained by the relative location of homes and workplaces and the roads and transit routes connecting them. Urban form does not, however, *determine* the pattern of flows.

One can envision two very different patterns of commuting flows taking place within the same urban form: in the first, people by and large commute short distances to employment districts close to their residences; in the second, people make longer commutes, bypassing nearby employment districts for more distant ones. In the first case, the minimization of commuting distances influenced residential and employment choices, while in the second, other factors would be more important. Empirical studies from a number of U.S. metropolitan areas indicate that many people make long commutes despite the fact that there are housing units that suit their needs in locations much closer to their workplaces.[3] (Giuliano 1995)

Urban form evolves over time, reflecting the locational decisions of many households and firms, the actions of developers and landowners, and planning decisions and incentives provided by various levels of government. Since the process is slow and place-specific, it is difficult to make empirical generalizations about the environmental costs and benefits of different patterns of urban development. This section

[3] One possible explanation is that convenience of commuting plays a relatively small role in determining a household's location choice. Other factors such as remoteness, prestige, and a preference for newer housing are at least as significant.

Box 8-5: National Capital Region: Strategies for Conforming to Federal Clean Air Standards

The Washington, DC, metropolitan area, which contains parts of Maryland and Virginia, is one of the fastest growing areas on the East Coast. Its most rapid growth is occurring on the metropolitan periphery. Vehicle-miles traveled are projected to grow by 76 percent by 2020, substantially faster than projected growth in either households or jobs.[1]

The metropolitan area is designated a serious nonattainment area for ground-level ozone pollution. For this reason the National Capital Region Transportation Planning Board (TPB), which serves as the metropolitan planning organization (MPO) for the region, was required under the Clean Air Act Amendments of 1990 to submit a plan to achieve a 15 percent reduction in emissions of volatile organic compounds (VOC). As part of the planning process, TPB analyzed the potential to reduce emissions and the relative costs of 59 transportation control measures (TCMs).[2]

The TCMs finally included in the plan had potential to reduce emissions, were relatively low in cost, and could be implemented quickly to meet reductions deadlines. One immediate TCM action was to allow right turns on red throughout the metropolitan region—a step estimated to reduce VOC by 0.39 tons per day at a cost of only $236 per ton.

Another TCM, funded for the 1996 to 2001 transportation improvement plan (TIP), is a ridesharing incentive program to upgrade the existing "Ride Finder" matching system and to establish satellite ridesharing associations at major employment centers. This measure is projected to lower VOC and nitrogen oxides emissions by 0.07 and 0.16 tons per day, respectively, at costs of about $13,000 per ton.

Another TIP measure will promote telecommuting through educational programs, technical assistance, and five new regional telecommuting network centers. The measure is projected to lower VOC emissions by 0.32 tons per day and NO_x emissions by 0.66 tons per day at costs of $6,500 and $3,500 per ton, respectively. A further measure approved for inclusion in the long-range plan is increased speed limit enforcement, which could reduce NO_x emissions by about 1.25 tons per day. (NO_x emissions tend to increase with speed.)

The table summarizes emissions forecasts for the year 2020 under a base scenario and a scenario that takes account of adopted TCMs. The reductions that can be attributed directly to TCMs are small compared with those that are attributable to changes in vehicle technology and emissions standards. Also, emissions of NO_x are projected to be higher with the TCMs than without them, perhaps due to increased average vehicle speeds. TPB is considering measures to address this problem. These include employer outreach for travel demand management measures, guaranteed ride home programs, and programs to remove older vehicles and increase the use of alternative fuel vehicles.

Projected Transportation Emissions for the COG-Modeled Area

	1990	2020 technology	2020 technology and TCMs[a]	TCMs alone
HC (tons/day)	225.47	123.82	121.52	–2.30
CO (tons/day)	2,148.25	1,338.22	1,303.13	–35.09
NO_x (tons/day)	272.11	236.05	239.02	2.97

[a] Includes elements of both the 1996–2001 Transportation Improvement Plan and the Constrained Long Range Plan.

KEY: COG = Council of Governments; TCM = transportation control measure.

SOURCE: National Capital Region Transportation Planning Board, *Conformity Determination of the Constrained Long Range Plan and the FY96-2001 Transportation Improvement Program for the Metropolitan Washington Region with the Requirements of the 1990 Clean Air Act Amendments* (Washington, DC: July 19, 1995), exhibit 16b.

[1] Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, *Conformity Determination of the Constrained Long Range Plan and the FY96-2001 Transportation Improvement Program for the Metropolitan Washington Region with the Requirements of the 1990 Clean Air Act Amendments* (Washington, DC: July 1995), exhibit 11: 22.

[2] Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, *Transportation Control Measures Analyzed for the Washington Region's 15% Rate of Progress Plan* (Washington, DC: July 1994).

reviews the relationship between urban form and transportation emissions in three ways: urban sprawl, changes in the road network, and local planning and design options that influence transportation choices.

▶ Urban Sprawl

Urban sprawl refers to the general deconcentration of population and employment in metropolitan areas. It is characterized by 1) an outward expansion of the metropolitan boundary that separates urban from rural land uses, 2) a general decline in intensity of urban land uses, as measured by population and employment densities, 3) highway or other transport networks that provide high connectivity among points, even in peripheral parts of the city, and 4) the segregation of residential from other land uses, with the greater part of residences locating in peripheral suburbs.

The term is most often associated with automobile-dependent suburban development in the post-World War II era. Americans with cars no longer needed to locate close to their jobs or to transit corridors. Certain elements of public policy, such as the construction of commuter roads and the tax deduction for mortgage interest, are also credited with promoting sprawl, although the general trend to deconcentration was evident before they came into force.

Sprawl has had a number of benefits. It made home ownership affordable to a larger segment of society and provided a highly mobile and flexible lifestyle away from the congestion and pollution of central cities. It also has its costs. For example, it is generally more expensive to provide infrastructure to low-density development. One recent study concluded that these incremental costs are not fully borne by suburban residents. (US Congress OTA 1995b)

Since low-density development and the segregation of land uses implies longer average trips, it may lead to increased energy use and emissions by automobiles. As shown in table 8-8, residents of high-density zones travel fewer miles annually than residents of low-density zones. These data, however, should be interpreted with caution. There may be socioeconomic differences affecting travel behavior between people living in high-density and low-density neighborhoods. Hence, it does not necessarily follow that the travel of suburbanites would fall to the level of city residents if suburban residential densities increased. Also, the densities at which a rapid decline in vmt are observed are quite high compared with the national average of 2,500 people per square mile in urbanized sections of metropolitan statistical areas. Furthermore, reductions in vmt do not necessarily translate into proportional reductions in emissions, since the number of trips also has an effect on emissions. (TRB 1995, 195-197)

Over the past 20 years, a number of studies looked at the question of whether sprawl leads to increased energy use and emissions. One influential study (Real Estate Research Corp. 1974) assessed the transportation requirements for a hypothetical new town under low- and high-density spatial design scenarios. It found that a high-density scenario was more energy efficient and less polluting than a low-density scenario. Further

TABLE 8-8: AVERAGE VEHICLE-MILES TRAVELED AT DIFFERENT LEVELS OF DENSITY

Density (pop/sq mile)	**Change in density** (percent)	**Vehicle-miles traveled** (vmt)	**Change in vmt** (percent)
1,280	–	6,500	–
2,688	110	6,500	0
6,400	138	5,500	–15
14,700	130	4,500	–18
33,280	126	2,500	–44

SOURCE: R. Dunphy and K. Fischer, "Transportation, Congestion, and Density: New Insights," paper presented at the 73rd annual meeting of the Transportation Research Board, Washington, DC, 1994.

evidence was provided by studies assessing alternative growth scenarios for specific urban areas, which also indicated significant energy savings, especially in transportation, from higher density development. (Carrol 1977, Roberts 1977)

More recent studies include cross-sectional studies of groups of cities and case studies on individual cities. (Anderson et al 1996) An international comparison of per capita gasoline consumption for 32 major cities concluded that a very high proportion of variation in gasoline consumption is explained by population density. (Kenworthy and Newman 1990) Despite methodological criticism (Gomez-Ibañez 1991), this study is frequently cited in support of arguments for denser urban development. A metropolitan case study of driving behavior in Perth, Australia, found that, despite the negative impact of congestion on fuel efficiency, people living in low-density areas used the most fuel per capita because they took more and longer trips. (Newman and Kenworthy 1988)

A simulation study on the Greater Toronto Area (IBI Group 1990) assessed the energy, environmental, and financial implications of various scenarios for the spatial distribution of urban growth. Its results indicate a strong positive relationship between the extent of sprawl and both energy consumption and environmental emissions. A different conclusion was reached by a simulation study of alternative transportation scenarios in Denver. (May and Scheurenstuhl 1991) It concluded that the benefits of denser development were largely offset by higher congestion.

Most of the studies were based on simulations of land-use scenarios in real or hypothetical cities, not experience. (Exceptions are Newman and Kenworthy 1988, Kenworthy and Newman 1990) Also, some only measure transportation energy consumption, which is an imperfect proxy for emissions.

While most studies contend that sprawl increases emissions, there is a counter argument that says that, in the long run, decentralized development could lead to *lower* emissions. The strong trend of decentralization in employment is resulting in a growing number of suburb-to-suburb commutes and a relative decrease in the proportion of suburb-to-central city commutes. (US Congress OTA 1995b) The pattern will vary among MSAs, but, in some MSAs, the average distance between homes and workplaces could decrease, especially where there are employment clusters in the metropolitan periphery. (Garreau 1991) Because commutes occur on less congested roads, commute duration may decrease even if commute distances do not (Gordon and Richardson 1994), and cars traveling in less congested conditions, and therefore traveling at higher average speed, will produce less emissions per mile (up to certain speeds and except for NO_x). (TRB 1995) Furthermore, a more dispersed pattern of driving will distribute emissions into a larger airshed, leading to lower pollutant concentrations. Although this may reduce some of the negative health effects, this does not necessarily imply that the total cost of damage from such pollution will be lower. Moreover, concentrated or dispersed emission of some pollutants, such as CO_2, makes little difference outside of the MSA as their impact is felt at the global scale. And while this argument is supported by evidence showing increasing average speed of commutes, and, hence, less congestion, it is questionable given the continued growth in the average length of commutes and the fact that sprawled development discourages alternatives to the SOV travel mode.

► Highway Infrastructure

The construction of new roads, or the expansion of existing roads, may affect emissions both directly and indirectly. Direct effects include both changes in the level of congestion, which affect emissions per vmt and increases in vmt.

Indirect effects relate to the long-term impact of road infrastructure on land-use patterns, whereby new roads may accelerate peripheral development and thus increase overall vmt.

If the number and pattern of trips in a metropolitan area could be held constant, new highway infrastructure would reduce congestion. This is true both for the expansion of existing roads and the construction of new roads. In general, reducing congestion can contribute to a reduction in emissions because of the high rates of emissions in stop-and-go situations. This general observation is tempered by two factors. The first is that cold start and hot soak emissions, which account for roughly half of VOCs emitted, are not affected by changes in traffic flow. The second is that NO_x emissions tend to increase as average speed increases. Given the ambiguity about the effect of new roads on emissions, the CAAA requires an analysis of the net impact of all infrastructure projects in nonattainment areas.

There is considerable research on the effects of expanding road infrastructure on peak period congestion and vmt. These studies suggest that growth in traffic is usually less than capacity added, even for long periods. (TRB 1995) Still, some of the increased road capacity is quickly taken up by new traffic during peak periods. Drivers may switch routes or change their commute from off-peak periods. Some may drop out of carpools or stop using public transportation. (Downs 1992) Other drivers, who previously elected not to travel because of congested conditions, may decide to make a trip when new capacity becomes available—a phenomenon called *induced demand*.

A recent study concluded that, given the difficulty of relating emissions to traffic flow and the counteracting effects of induced demand, current analytical models are not able to determine whether a new highway has a positive or negative impact on emissions, even in the short run. (TRB 1995) Whether this points to the need for better models (Replogle 1995) or whether it means that the problem is too complex to permit definitive analysis remains unclear.

Over the longer term, the addition of new road capacity may encourage new housing subdivisions or other development at the metropolitan periphery that generate more traffic and vmt. (Wegener 1986) A number of approaches have been taken to assess the magnitude of this effect. These include studies that relate changes in land use and land values to proximity to new highways, and studies that compare development patterns in areas where new roads have been added with areas where they have not. These studies face a number of methodological difficulties because of the time lags involved, the difficulty of making apt comparisons, and the fact that numerous factors affect land-use patterns simultaneously. There is also a cause and effect problem: do new roads promote new development or does new development create a political demand for new roads? Taken together, the results of these studies are mixed, with earlier studies (in the 1950s and 1960s) indicating greater impacts than more recent studies. (TRB 1995) Assessing the indirect impacts of new highways on emissions, rather than just land-use patterns, would be even more difficult.

The general question of how new highways affect emissions and air quality is a significant issue, especially given the federal role in highway funding and in air pollution control. Once a highway is built, any negative environmental impacts could be felt for decades to come. If the environmental effects are small, however, restraint of new highway construction could impede economic growth and incur high congestion costs. This is an important area for further research.

Land-Use Planning and Design

Land-use planning and design is sometimes regarded as a transportation control measure because the layout of new development and the rehabilitation of existing built-up areas may affect travel behavior, and thus vmt and trips, and, ultimately, emissions. Given the complex and long-term nature of changes in land-use patterns, it is difficult to evaluate emissions reductions potential or cost-effectiveness of land-use planning as a TCM. The previously discussed Apogee study on TCMs concluded that over the long run, significant changes in land-use patterns had a greater potential for reducing travel than any of the conventional TCMs. (Apogee Research, Inc. 1994, 28)

A number of communities are now adopting planning principles that break with the standard pattern of suburban development. While conventional plans employ low densities and segregation of land uses, these new principles stress higher development densities with access to green spaces and mixed land uses. The motivations for this shift include the need to reduce municipal service costs, the desire to protect agricultural and open-space areas, and the desire to recreate the ambiance of traditional urban or small town communities. One of the most important motivations is to reduce the dependence of suburban residents on automobile travel, thereby reducing emissions. (Bank of America 1995)

Land-use planning and design measures are not specifically called for as ways to reduce emissions under the CAAA. Land-use control has traditionally been viewed as a local matter. Also, the magnitude of the effect of land-use measures on emissions is uncertain. To the extent that such planning can reduce emissions, the reduction will come over a period of several decades. Land-use measures may require cooperation of many local government authorities, and may place significant restrictions on the activities of land developers. As such, they are often controversial and difficult to implement from a political perspective. Still, land-use planning approaches are being examined in various locales.

Transit-oriented development (TOD) is a general class of plans for urban and suburban areas that allow residents to meet their daily mobility needs by travel modes other than SOVs. One critical element of TOD is density. Most people will not walk more than about one-quarter mile from their homes to a bus stop. The more widely spaced the homes, the fewer commuters that live within a reasonable walking radius of each stop.

Density, however, is not the only concern. The layout of streets in conventional suburban residential subdivisions makes extensive use of curved roadways and cul-de-sacs. Although cul-de-sacs reduce traffic on certain roadways, they also make it difficult to establish direct bus routes to serve new residential areas. For this reason, some California jurisdictions prohibit cul-de-sacs in new subdivisions. (Dyett 1991)

A goal of TOD is to lay out high- to medium-density residential areas in ways that maximize access to rail transit routes and stations. In addition to promoting the use of transit for commuting trips, TOD may encourage walking and bicycle trips for service and recreational activities. This can help reduce the number of short automobile trips which, because of cold start and hot soak emissions, can have a large impact on emissions. Shops, schools, parks, and public service facilities are located within short distances of homes, and may be clustered around transit stations. Walking and bicycling are also encouraged by design features of roadways and the design of "pedestrian-friendly" commercial areas rather than the typical suburban plaza with its large parking lots. (Calthorpe 1993) Critics argue, however, that with shorter distances trip-making is less costly in terms of time, so residents who do not switch to non-auto modes may actually make more trips. (Bae and Richardson 1994)

While TOD is too new to permit direct analysis of its impact on travel behavior, its supporters point to comparisons of older neighborhoods that conform with TOD principles with newer, low-density suburban neighborhoods. For example, researchers in the San Francisco Bay Area have compared older suburban town centers, which embody many TOD characteristics, with suburban tract developments. They found that households in the older neighborhoods made 9 trips per day versus 11 in the tract developments. In the older neighborhoods, 64 percent of trips were by car, 19 percent were by bicycle or walking, and 17 percent were by transit. The corresponding proportions in the tract development were 86 percent by car, 11 percent by bicycle or walking, and 3 percent by transit. (Calthorpe 1993, 48) (This comparison should be viewed with some caution as it does not control for socioeconomic differences between residents.)

The success of TOD will depend first on its ability to deliver the kind of change in travel behavior implied by this comparison, and second on its acceptance in the marketplace. A detached house on a large lot is the housing goal of many Americans. It is not clear how many suburban residents will opt for multifamily dwellings or smaller yards. Evidence will soon be available as many TOD projects come to completion, especially in California. San Diego and Sacramento have both incorporated TOD design guidelines into their regional plans, and there are a number of TOD projects at various stages of development. Also, the Portland, Oregon, metropolitan area is currently considering adoption of a long-term plan in which TOD principles are central (see box 8-6 at the end of this chapter).

The design of housing developments around transit services can only be successful if the residents have jobs that are accessible by transit. Most employers outside central cities locate either independently or as part of an industrial park on a large site surrounded by parking areas. These sites often are arranged in linear patterns along major roadways. Thus, the average distance between each place of employment and its nearest neighbor is great. By contrast, urban employment zones traditionally served by public transportation may have dozens of places of employment within an easy walk of each transit stop. Providing service to dispersed workplaces is possible through use of small shuttles that stop at every company's door. Such shuttles, however, are relatively slow and have high labor costs, since the ratio of drivers to riders is higher than in regular buses.

If workplaces are clustered into suburban employment centers, it may become possible to lay out efficient transit routes and serve a large number of employers with each stop. If such centers could be laid out along light-rail lines, and included shopping and recreational facilities, some demand for the transit service during off-peak periods might be generated. (Cervero 1991)

It is probably too early to say how effective land-use planning and design can be in reducing automobile emissions. One reason for this is that these changes are incremental by their very nature. It is very difficult to change the land-use patterns in an existing built-up area. Thus, even fundamental changes in the design of new developments would have only small changes in the overall density and structure of the metropolitan area. (Downs 1992, 80) Only after many years could changes in land-use planning and design be expected to have a major impact on aggregate metropolitan emissions. Because urban environmental problems are likely to be around long into the future, more research is needed to find out whether planning can play a major role in a long-term strategy.

Conclusions

Federal environmental laws encourage many local governments and MPOs to apply TCMs to supplement technology-based strategies to restrain emissions. The information that is currently available suggests that the contributions of TCMs to emissions reductions in most metropolitan areas may be modest when compared with the major reductions that have occurred because of the tighter emissions standards that have been achieved through technology. There is, however, still some uncertainty in this conclusion. Most current analyses take the form of projections based on limited experience and empirical data. More analyses of situations where TCMs have been implemented is needed. Also, more analyses are needed of the potential emissions reduction from the simultaneous application of several TCMs, since synergies or overlaps between measures could affect outcomes.

The TCMs that have received the greatest attention are short- to medium-term measures. There are a number of longer term integrated land-use and transportation planning measures that may also figure in the reduction of emissions in the next century. Highway construction, or the decision not to build a highway, can be seen as a TCM in the sense that it affects the volume and distribution of traffic, and thereby aggregate emissions. Assessment of the emissions impacts of highways is required under the CAAA. The current state of analytical modeling can only address the direct, short-term impacts of highways on vmt, however, and even then imperfectly. The longer run impacts that emerge from the interaction of highway networks and land-use patterns are much more difficult to gauge.

Elements of land-use planning may also affect travel patterns and emissions. On a broad scale, overall development may affect trip lengths, mode split, and congestion. At a more localized scale, transit-oriented development has been proposed as a means to reduce the dominance of the SOV mode. The impact of these measures is uncertain at this time. It is likely, however, that novel approaches to land-use development will soon be applied in a number of metropolitan areas, creating the possibility for empirical analyses.

Finally, evidence that individual TCMs have relatively modest impacts does not necessarily imply that they will not play an important role in the long-term strategy for emissions reduction. Complementary TCMs, taken together, may have higher (or lower) impacts than current research indicates. Also, it should not be assumed that the preferences of the current generation of Americans, such as the preference for large suburban lots and SOV transportation, will be carried over into future generations. Demographic changes and changes in tastes and attitudes may increase the popularity of such options as transit-oriented development at some future date.

Box 8-6: Portland, Oregon: Exploring the Transportation/Land-Use Link

Portland, Oregon, is a relatively fast-growing metropolitan area. Its population increased by over 13 percent between 1980 and 1990, and further increases are projected well into the next century. In the late 1980s, regional authorities proposed the construction of a major circumferential highway, the "Western Bypass." The purpose of the highway was not to alleviate existing congestion problems, but to provide access for the projected increase of 160,000 people in as yet undeveloped areas of Washington County on the western periphery of the metropolitan area. The anticipated development was expected to follow the conventional pattern of low-density residential subdivisions with a high degree of segregation from commercial and other land uses.

An environmental advocacy group, 1000 Friends of Oregon, opposed the Western Bypass on the grounds that it violated the Urban Growth Boundary established around Portland under Oregon state law. In the wake of litigation that followed, the Oregon Department of Transportation asked 1000 Friends of Oregon to propose an alternative plan to accommodate the projected growth in the metropolitan area. The result is a demonstration research project called "Making the Land-Use, Transportation, and Air Quality Connection." The project, which was to become known by the acronym LUTRAQ, received financial support from the U.S. Environmental Protection Agency, the Federal Highway Administration, and a number of private foundations.

The goal of LUTRAQ was to design a regional development plan for Washington County that would provide new residents with adequate transportation access to employment and other services without construction of the Western Bypass. The design strategy focused on transit-oriented development (TOD) principles and economic incentives to discourage single-occupancy vehicle travel.

The proposed plan includes a major light-rail transit corridor extending west from downtown Portland. Feeder buses would serve this corridor, along with a demand responsive "dial-a-ride" system for areas not served by fixed route transit. Limited expansion of existing arterial roads is also part of the plan.

The most innovative aspects of LUTRAQ relate to land-use development. The goal is to create a more structured, transit-supportive land-use pattern without violating the suburban character of the region. Four types of nodal developments are included in the plan: mixed-use centers developed at existing town centers through redevelopment and infill; urban TODs located on previously undeveloped sites along the light-rail corridor; neighborhood TODs connected to the light rail by feeder buses; and secondary areas located no more than one mile from TODs that apply more traditional suburban planning. Mixed-use centers and urban TODs both have an average density of 15 houses per acre, the neighborhood TODs have an average density of eight units per acre, and secondary areas have typical suburban densities.[1] The TOD design also incorporates elements to promote a pedestrian-friendly environment, in order to reduce local automobile trips and vehicle-miles traveled (vmt).[2]

Market analysis was conducted to ensure that the housing mix envisioned by LUTRAQ fit the demand profile of people likely to move into Washington County. To be consistent with market demands, 37 percent of the housing units were planned as multifamily and 67 percent as single-family. It was projected that with appropriate zoning, permit allocations, and fiscal incentives, all the multifamily units and 55 percent of single-family units could be located within mixed-use centers and urban and neighborhood TODs. The balance of single-family homes would be in the secondary areas.[3]

The LUTRAQ plan also includes two financial incentives to discourage SOV travel. The first is a mandatory $3.00 per day parking charge at workplaces and the second is the provision of free transit passes for commuters.

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[1] For a review of TOD concepts, see Peter Calthorpe, *The Next American Metropolis* (New York, NY: Princeton Architectural Press, 1993).
[2] Parsons, Brinckerhoff, Quade, and Douglas, Inc., "The Pedestrian Environment," prepared for 1000 Friends of Oregon, December 1993.
[3] Market Perspectives, Hebert/Smolkin Associates, Inc., *Market Research: Volume 3A*, prepared for 1000 Friends of Oregon (Portland, OR: 1992).

(continued)

Box 8-6 (cont'd): Portland, Oregon: Exploring the Transportation/Land-Use Link

One of the main tasks of the project was to compare the projected transportation behavior and emissions under the LUTRAQ proposal with what would be expected if the Western Bypass were constructed. Some estimates for travel behavior effects are presented in table 1. Here LUTRAQ I and LUTRAQ II refer to the plan with and without the financial incentives, respectively. It is interesting to note that the difference in mode share between the Bypass scenario and the LUTRAQ scenario is highly dependent on the inclusion of financial incentives. The analysis also indicates that the LUTRAQ option results in a reduction in vmt and trips, but an increase in peak vehicle-hours of delay. The LUTRAQ project shows that land-use planning and other transportation control measures can be used together to identify and plan potentially viable alternatives to major transportation infrastructure expansion. The expected changes in travel behavior are, however, relatively minor in light of the extensive land-use changes proposed under the plan.[4]

Table 1: Mode Shares Under Western Bypass and LUTRAQ Scenarios

	Mode share (percent)		
Type of trip	**Bypass**	**LUTRAQ I**	**LUTRAQ II**
Home-based work trips			
Walk	2.5	3.5	3.5
Single-occupancy vehicle	75.1	72.7	63.9
Carpool	13.6	13.8	19.7
Transit	8.8	10.0	12.8
Total home-based			
Walk	4.9	5.7	5.7
Automobile	85.4	84.2	83.4
Transit	9.7	10.2	10.9
Total nonhome-based			
Walk	0.3	0.5	0.5
Automobile	99.0	98.8	98.8
Transit	0.7	0.8	0.8
All trips			
Walk	3.7	4.5	4.5
Automobile	89.0	87.6	87.0
Transit	7.3	8.0	8.6
Daily vehicle-trips per household	7.68	na	7.09
PM peak vehicle-miles	679,390	na	586,660
PM peak vehicle-hours	19,920	na	18,380
PM peak vehicle-hours delay	1,670	na	1,950

NOTE: na = not available.
SOURCE: Genevieve Giuliano, "Land Use Impacts of Transportation Investments: Highway and Transit," *The Geography of Urban Transportation*, Susan Hanson (ed.) (New York, NY: Guilford, 1995), ch. 13, tables 13.6 and 13.7.

While LUTRAQ was only a demonstration research project, at least some of the land-use and transportation principles that it endorsed are being adopted in the Portland metropolitan region. Portland was a marginal nonattainment area for ozone, and a moderate nonattainment area for carbon monoxide (CO). Federal emissions standards, along with local initiatives for vapor recovery and vehicle inspection have now brought the region into maintenance status for both pollutants. Given a projected annual growth rate of 2.2 percent for vmt, emissions are expected to increase by the end of the decade. In response to the danger that Portland would be unable to maintain attainment status, a state task force devised a plan to reduce emissions of volatile organic compounds (VOC) and nitrogen oxides (NO_x) by 37.1 percent and 20.6 percent, respectively, by the year 2007 (these are reductions from projected emissions under federal emissions restrictions). Some of the reductions would be achieved by requiring pedestrian-, bicycle-, and transit-friendly land use for all new construction. The majority of the projected

[4] Genevieve Giuliano, "The Weakening Transportation-Land Use Connection," *Access*, vol. 6, 1995, pp. 3–11.

BOX 8-6 (cont'd): PORTLAND, OREGON: EXPLORING THE TRANSPORTATION/LAND-USE LINK

reductions are due to vehicle inspection and maintenance programs, with emissions fees and mandatory employer trip reduction also contributing to significant reductions.[5]

More extensive use of integrated transportation and land-use planning is now under review as part of a long-term plan for metropolitan Portland called "Region 2040." As a result of a 1992 referendum, Portland's Metro Planning Department was asked to develop a plan for accommodating growth without sacrificing the quality of life, natural areas, air quality, and water quality. As part of this process, Metro analyzed four land-use and transportation scenarios to accommodate an additional 1.1 million residents by the year 2040. The Base Case scenario represents the growth patterns that would occur if recent development patterns were to continue. It includes dispersed and segregated land-uses and major highway construction (including the Western Bypass). This scenario, however, would not be permitted under recently enacted land-use regulations. Concept A is a scenario for dispersed development—requiring a significant extension of the Urban Growth Boundary—which complies with current land-use rules. Concept B is a dense, transit-oriented growth scenario, which does not violate the current Urban Growth Boundary. It incorporates many of the same design criteria as LUTRAQ. Concept C restricts most growth to the Urban Growth Boundary, but also opens up several "satellite cities" for development.[6] Concept B

[5] State Task Force on Motor Vehicles Emissions Reduction in the Portland Area, *Final Report: Volume 1 Findings and Recommendations* (Portland, OR: Oregon Department of Environmental Quality, February 1993).

[6] Metro Planning Department, *Region 2040 Concepts for Growth: Report to Council* (Portland, OR: June 1994).

(continued)

TABLE 2: COMPARISON OF REGION 2040 GROWTH CONCEPTS

Category	1990	Base Case	Concept A	Concept B	Concept C
Buildable acres	53,736	154,974	104,325	65,006	78,574
Growth outside urban growth boundary (percent)	–	17	29	0	37
Density (people per acre)	8.9	7.9	9.8	12.4	9.2
Single-family/multifamily (percent)	70/30	70/30	74/26	60/40	69/31
Average vmt per capita	12.4	13.04	12.48	10.86	11.92
Auto/transit/walk-bike (percent)	92/3/5	92/3/5	91/4/5	88/6/6	89/5/6
Lane-miles	5,304	6,777	6,377	5,557	6,116
Transit service hours	4,965	9,575	12,322	13,192	12,553
Congested roadway-miles (am peak)	150.5	505.6	682	642.6	403.9
Emissions (kg/day)					
Carbon monoxide: winter	835,115	614,451	613,537	579,579	569,091
Carbon monoxide: summer	574,708	528,601	525,133	496,017	487,188
Hydrocarbon: summer	177,857	70,700	69,810	66,375	65,745
Nitrogen oxides: summer	80,452	94,024	90,987	83,817	86,988

KEY: vmt = vehicle-miles traveled; kg/day = kilograms per day.

SOURCE: Metro Planning Department, *Region 2040 Concepts for Growth: Report to Council* (Portland OR: June 1994), p. 88.

BOX 8-6 (cont'd): PORTLAND, OREGON: EXPLORING THE TRANSPORTATION/LAND-USE LINK

incorporates the most transit-oriented transportation infrastructure plan, while Concept A incorporates the most roads-oriented plan, with Concept C in an intermediate position.[7]

The concepts were evaluated on a number of factors, including air quality. As a result of federal, state, and local emissions control policies, estimates of CO and VOC emissions for all scenarios were below the 1990 levels (see table 2). However NO_x estimates for all four scenarios are higher than the 1990 levels. The least dispersed scenarios (concepts B and C) had the best estimated performance. A summary of the results of this analysis was distributed to every household in the Metro Region. It is now up to Metro Council to decide which of the three concepts (or what combination of elements of the three) to adopt as its long-range growth plan.

[7] Metro Planning Department, Regional Transportation Planning, *Region 2040: Transportation Analysis of the Growth Concepts* (Portland, OR: July 1994).

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